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Measurements with a recombination chamber made at the CERN-EC high energy reference field, CERF, in August 2001

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Abstract

The ambient dose equivalent, H*(10), and the quality factor, Q, were measured in a mixed radiation field during the August 2001 CERF run, using a REM-2 recombination chamber and a HANDI tissue equivalent proportional counter for comparison. There was good agreement between the two instruments. Experiments with the recombination chamber showed that the orientation of the chamber in the field did not affect these measurements. For lower beam intensities a lower quality factor was observed due to low LET radiation out of the experimenter's control.

Introduction

Measuring the dose equivalent in mixed radiation fields is difficult, as the quality factor must be determined. A possible solution has been described by Golnik and Zielczynski[1] who propose a method of determining the quality factor, as defined by ICRP 21. Based on measurements with a TE-ionisation chamber, they define a recombination index or radiation quality Q_4, which approximates Q, as defined by ICRP 21, to within 20%. This is evaluated using the following formula,

$$Q_4 = \frac{1 - f_{mix}}{1 - f_\gamma} \qquad (1)$$

where f_γ is the ion collection efficiency, at a voltage U_R, in a reference γ-field from a ^{137}Cs source, and f_{mix} is the ion collection efficiency at the same voltage in an unknown radiation field. U_R, the recombination voltage, should be chosen so that f_γ is 96%.

To adjust this procedure to the quality factors defined in ICRP 60 Golnik proposes the use of a new quantity Q_{4new} [1] which is a function of Q_4 such that,

$$\begin{aligned} Q_{4new} &= Q_4 \\ Q_{4new} &= Q_{ICPR60}(L_R) \quad \text{for} \quad 5 < Q_4 < 11 \quad \text{and} \quad Q_4 > 20 \qquad (2) \\ Q_{4new} &= 20 \quad \text{for} \quad 11 \le Q_4 \le 20 \end{aligned}$$

where $L_R = \dfrac{L_0 f_\gamma Q_4}{1-(1-f_\gamma)Q_4}$ is a single effective LET value which replaces the LET spectrum for the radiation, and $L_0 = 3.5 \quad \text{keV}/\mu\text{m}$.

It should be noted that for $Q_4 < 5$ there is no difference between Q_{ICPR60} and Q_{ICPR21} as measured by the recombination chamber, this is perhaps unrealistic. Q_{ICPR60} values as a function of LET are given in Table 1.

Table 1 Relation between quality factor and LET recommended in ICRP publication 60, cit. [2].

L in water [keV/ µm]	Q(L)
<10	1
10-100	0.32L-2.2
>100	$300/\sqrt{L}$

Recombination methods have previously been tested in mixed radiation fields, and given results consistent to those measured by other instruments [3, 4, 8, 9]. However, most previous work has evaluated quantities according to the old ICRP 21 definition of the quality factor, or used a more complicated procedure to determine ICRP 60, where the saturation curve of the chamber in the mixed radiation field is compared to the saturation curve in a reference γ-field[8,9].

Experimental Set Up

CERN has three REM-2* recombination chambers, numbers 021, 027 and 004. These were calibrated in the CERN-TIS/RP calibration hall[5]. Measurements with the recombination chambers were made at the CERN-EC High Energy Reference Field Facility (CERF-field). The neutron component of the field is well characterised as a result of measurements made by groups from across Europe using a wide range of active and passive detectors, and by Monte Carlo simulations carried out at CERN.[6] Unfortunately the Monte Carlo simulations only model radiation produced in the target, so they are not relevant for the γ and muon components of the field coming from elsewhere in the H6-experimental hall.

The field is situated on one of the secondary beams from the Super Proton Synchrotron (SPS). A pulsed hadron beam, with a period of 16.8 s and a momentum of 120 GeV/c, is fired onto a copper target, within a radiation cave. The resulting secondary particles are filtered through either 80 cm of concrete or 40 cm of iron roof shielding giving almost uniform fields over two 2x2 m areas. These are divided into grids as shown in Figure 1.

An air-filled precision ionisation chamber (PIC) is used to measure the intensity of the primary beam and results are normalised to its count rate. Typical dose equivalent rates over concrete are 0.3 nSv per PIC count, and the intensity of the beam can be altered between 5 and 600 µSv/h[6], by adjusting collimators C3 and C5 in the beam line.

The radiation produced is mostly neutrons, but there are also gammas, other hadrons, electrons and muons. The resulting radiation field is similar to the cosmic ray field at 10-20 km altitude, and so can be used for testing equipment to be used in inflight measurements on aircraft. [7]

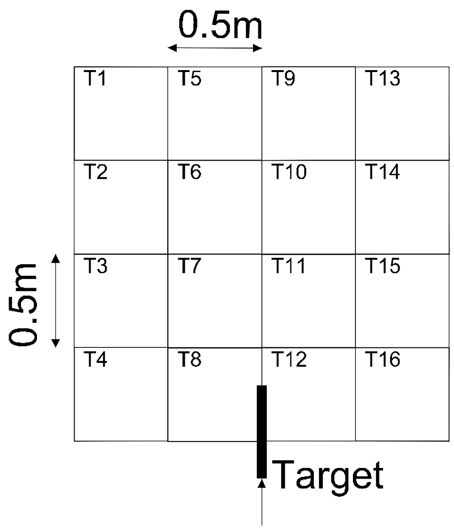

Figure 1 Geometry of the CERF experiment [7].

* REM-2 Chamber, ZZUJ "Polon"-Radiation Dosimetry Instrument Division, Bydgoszcz, Poland.

Measurements at Different Positions on the Concrete Roof Shielding

Measurements at CERF were made with REM-2 chamber 027, as it has the highest sensitivity of the CERN chambers, and also with a HANDI tissue equivalent proportional counter (TEPC) for comparison. TEPC are known to give good results in this type of radiation field and so are often used as a reference.

Measurements of *Q* and *H*(10)* were made over concrete at positions T4, T6, T8, T10 and T12, with the recombination chamber and the HANDI. The maximum beam intensity with collimators C3 and C5 at ±10, corresponding to around 7500 PIC counts per spill was used. Values for *Q* and *H*(10)* were calculated both for ICRP 21, Table 2, and ICRP 60, Table 3, to allow comparison with measurements from previous years. In Figure 2 the results of the quality factor Q for the detectors are presented. Figure 3 shows the results for H*(10) normalized to the PIC counts at different measurement positions.

Table 2 Measurements of ambient dose equivalent, *H*(10)*, and quality factor, *Q*, over the concrete roof shielding at CERF. Measurements are with the HANDI TEPC and the REM-2 recombination chamber and evaluated according to ICRP 21. Collimators C3 and C5 at ± 10, corresponding to 7500 PIC counts per spill.

Position	Q Recombination Chamber	Q HANDI	H*(10) Recombination Chamber Sv/PIC count	H*(10) HANDI Sv/PIC count
T4	3.25 ± 0.33	3.52 ± 0.13	$(2.49 \pm 0.25)\text{x}10^{-10}$	$(2.14 \pm 0.14)\text{x}10^{-10}$
T6	2.74 ± 0.51	3.20 ± 0.02	$(3.67 \pm 0.68)\text{x}10^{-10}$	$(3.32 \pm 0.05)\text{x}10^{-10}$
T8	2.31 ±1.16	3.29 ± 0.19	$(2.42 \pm 1.21)\text{x}10^{-10}$	$(2.61 \pm 0.18)\text{x}10^{-10}$
T10	2.64 ± 0.26	3.42 ± 0.11	$(3.93 \pm 0.38)\text{x}10^{-10}$	$(3.47 \pm 0.14)\text{x}10^{-10}$
T12	2.63 ± 0.26	3.28 ± 0.09	$(3.21 \pm 0.32)\text{x}10^{-10}$	$(2.77 \pm 0.06)\text{x}10^{-10}$

Table 3 Measurements of ambient dose equivalent, *H*(10)*, and quality factor, *Q*, over the concrete roof shielding at CERF. Measurements are with the HANDI TEPC and the REM-2 recombination chamber and evaluated according to ICRP 60. Collimators C3 and C5 at ± 10, corresponding to 7500 PIC counts per spill.

Position	Q Recombination Chamber	Q HANDI	H*(10) Recombination Chamber Sv/PIC count	H*(10) HANDI Sv/PIC count
T4	3.25 ± 0.33	3.93 ± 0.13	$(2.49 \pm 0.25)\text{x}10^{-10}$	$(2.22 \pm 0.14)\text{x}10^{-10}$
T6	2.74 ± 0.51	3.65 ± 0.08	$(3.67 \pm 0.68)\text{x}10^{-10}$	$(3.52 \pm 0.02)\text{x}10^{-10}$
T8	2.31 ± 1.16	3.67 ± 0.18	$(2.42 \pm 1.21)\text{x}10^{-10}$	$(2.91 \pm 0.17)\text{x}10^{-10}$
T10	2.64 ± 0.26	3.79 ± 0.09	$(3.93 \pm 0.38)\text{x}10^{-10}$	$(3.77 \pm 0.12)\text{x}10^{-10}$
T12	2.63 ± 0.26	3.62 ± 0.08	$(3.21 \pm 0.32)\text{x}10^{-10}$	$(3.05 \pm 0.05)\text{x}10^{-10}$

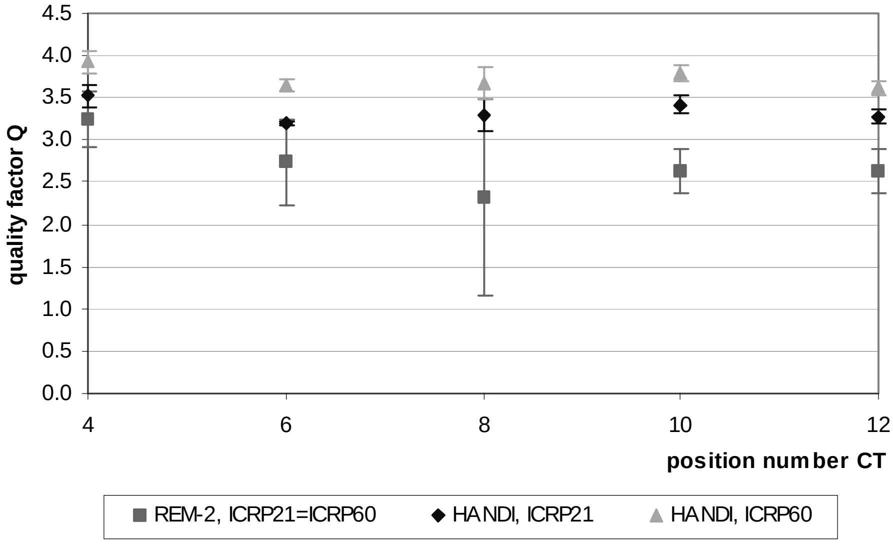

Figure 2 Quality factor Q determined with the recombination chamber REM-2 and the TEPC HANDI at different positions on the concrete shielding. The results are shown according ICRP21 and ICRP60.

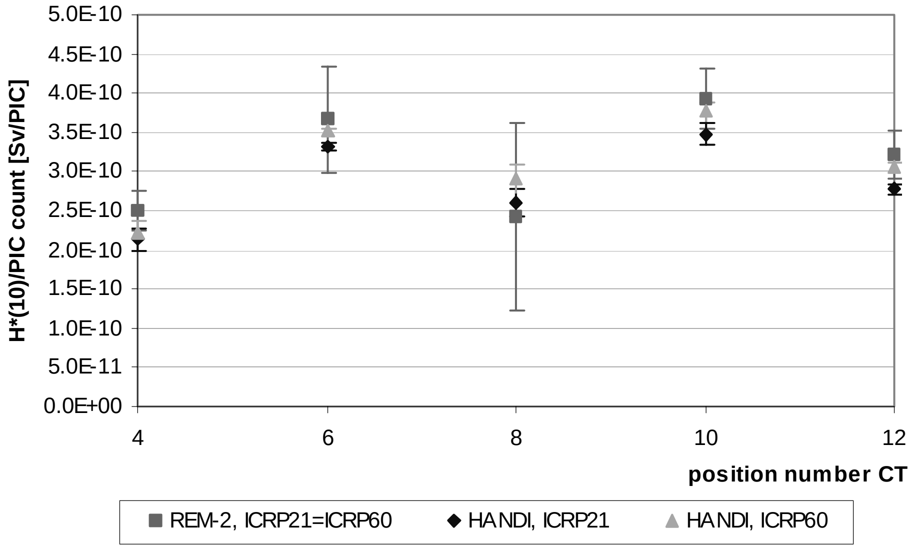

Figure 3 H*(10) per PIC count measured with the HANDI and the REM-2 chamber at certain positions on the concrete shielding

There is good agreement between *H*(10)* as measured by the recombination chamber and the HANDI for ICRP 21 and ICRP 60, although the recombination chamber gives a slightly higher result for position 12 according to ICRP 21. With the exception of positions 10 and 12 quality factors according to ICRP 21 also agree within the error bounds, while for ICRP 60 the quality factors measured by the recombination chamber are lower than those measured with the HANDI.

The error estimates for the HANDI measurements include statistical uncertainties only and no uncertainties due to calibration. From this it follows that smaller error bounds are stated for the HANDI measurement than for the recombination chamber. The error for position

T8 is larger because of instabilities of the beam while this measurement was made. By the reason of restricted space in the measurement positions, measurements with different instruments were not made simultaneously hence this in not reflected in the HANDI results.

Orientation of the chamber in the field

Measurements were made with the chamber in position 8, with the long axis of the chamber at 3 different orientations. The quality factors and ambient dose equivalents measured at different orientation are the same within the error bounds, Table 4. This is consistent with measurements made in position 6 over the iron roof shielding by Golnik 1993, where the absorbed dose measured by the chamber in horizontal and vertical orientations, was found to be the same to within 0.5%, and the quality factor was the same within 2% [8].

Table 4 Measurements of ambient dose equivalent, *H*(10)*, and quality factor, *Q*, over the concrete roof shielding at CERF. Measurements are with the REM-2 recombination chamber at different angles to the horizontal and evaluated according to ICRP 21. Collimators C3 and C5 at ± 10, corresponding to 7500 PIC counts per spill.

Orientation	Q	H*(10) Sv/PIC count
Vertical	2.77± 0.55	$(3.71 \pm 0.74)x10^{-10}$
Horizontal	2.62 ± 0.31	$(3.83 \pm 0.47)x10^{-10}$
35°	2.84 ± 0.53	$(3.56 \pm 0.09)x10^{-10}$

Measurements at Different Intensities

The quality factor and ambient dose equivalent were measured at 2 different intensities in position 8, Table 5. For the lower intensity it can be seen that the quality factor is closer to 1 and that the ambient dose equivalent per PIC count is greater by about a factor of 4. This is likely to be due to muons from other parts of the SPS, which are not detected by the PIC.

Table 5 Recombination chamber measurements of ambient dose equivalent, *H*(10)*, and quality factor, *Q*, over the concrete roof shielding at CERF for different beam intensities. Results evaluated according to ICRP 21.

Settings C3, C5	Q	H*(10) Sv/PIC count
± 10 (2500 PIC counts/spill)	2.35 ±1.18	$(2.45 \pm 1.24)x10^{-10}$
± 2 (100 PIC counts/spill)	1.01 ± 0.15	$(8.61\pm1.25)x10^{-11}$

Golnik 1998 [9] also observed that the quality factor depended on the beam intensity. This was attributed to low LET radiation, concurrent with the beam pulse and not directly under the experimenter's control. Consequently the quality factor increased as the beam intensity increase, Figure 4 [9]. As the source of this concurrent radiation is unknown, it is unclear how it varies in time and if it is the same during this experimental run as in 1998. Nevertheless a comparison with the 1998 results was attempted. The beam intensity was slightly higher than for the 1998 measurements but the result looks plausible, Figure 2, if the concurrent radiation is the same.

In addition the dark current was measured during a time of complete beam loss in the SPS, when there should be no stray muons. It was found to be around 10 pC, this is higher than the 3 pC measured during calibration[5], due to a higher gamma background in the experimental hall.

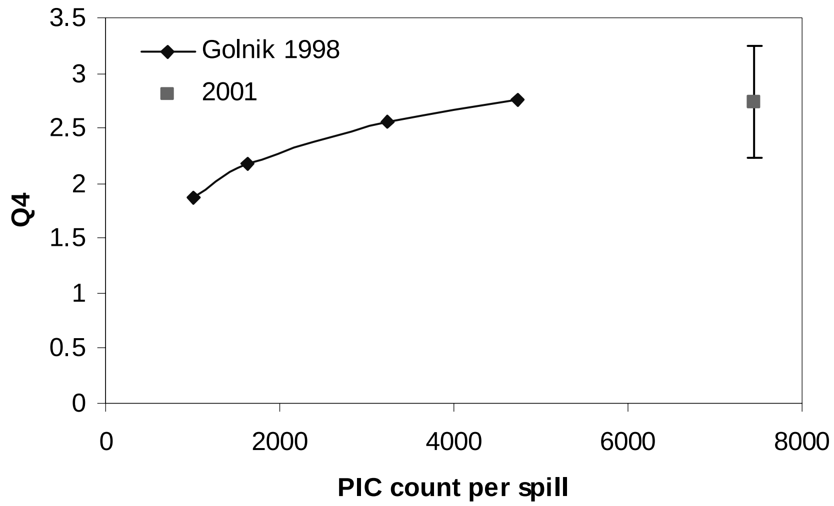

Figure 4 Recombination index of radiation quality Q4 measured at different intensities of the beam on the target for the top concrete T6 position. The results of this experimental run squares, Golnik 1998[9], rhombi.

Conclusions

Comparisons with the Monte Carlo simulations for the field are not possible as they only consider the radiation produced in the target, and not the concurrent low LET radiation, which is also detected by the recombination chamber. As a result the recombination chamber measurements can only be compared to those made with other instruments.

Initial results from the CERF experiment suggest that the recombination chamber can be used for measurements of ambient dose equivalent *H*(10)*, and quality factor according to ICRP 21. However quality factors evaluated according to ICRP 60 are more than 20% lower for the recombination chamber than the HANDI and should be treated with caution if the HANDI is considered as a reference. It is possible that this could be solved by a modification of the function Q_{4new}, and the conversion Q_4 to Q_{4new} should be tested in different radiation fields.

The orientation of the recombination chamber does not affect the values of $H^*(10)$ and Q measured.

Acknowledgement

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